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Observation of Liquid Particles at -65° in a Polar Cirrus

Del Guasta Massimo, Marco Morandi, Leopoldo Stefanutti,
Stefano Balestri, Francesco Castagnoli
Istituto Ricerca Onde Elettromagnetiche CNR Florence (Italy)

Esko Kyro, Markku Rummukainen
Sodankyla Observatory, Finnish Meteorological Institute (Finland)

Vincenzo Rizi, Fabrizio Masci
Universita' dell'Aquila, (Italy)

Bernhard Stein, Berndt Mielke
Freie Universitat Berlin (Germany)

Renaud Matthey
Observatoire Cantonal Neuchatel (Switzerland)

INTRODUCTION

It is widely accepted that pure water cannot exist as a liquid below about -40°. Theoretical and laboratory studies confirm this behaviour for pure water. Liquid droplets have been seldom observed in cirrus clouds down to about -50°C. The LIDAR technique can help to find out unusual supercooled clouds, when the depolarization technique is implemented: the presence of non-depolarizing layers in a cloud is indicative of a very special scattering media: scattering particles must have a symmetry axis oriented along the laser beam. This is possible either with spherical droplets or ice plates horizontally oriented. In this work, a -65°C cold, non-depolarizing cloud observed in Finland is studied, concluding that supercooled droplets are responsible for the absence of depolarization in most of the cloud. This is the coldest supercooled cirrus ever observed.

THE MEASUREMENT

A LIDAR system operated in Sodankyla (Finland) during the Second European Stratospheric Arctic and Midlatitude Experiment (SESAME). The system allowed the simultaneous measurement of clouds at three wavelengths (355, 532, and 750 nm). The results concerning cirrus clouds were compared with the large statistic of LIDAR cirrus data collected both in the Antarctic [Del Guasta et al., 1993] and in the Arctic [Del Guasta et al., 1994] with a similar LIDAR.

Most of the high cirrus observed in Sodankyla during SESAME showed "usual" depolarization values, in the range 10-30% (depolarization is here defined as the ratio between the perpendicular and the parallel aerosol volume backscattering). On a very particular occasion (February 12, 1995), a cirrus layer at 10 km showing no depolarization for most of the time was observed from 16:00 GMT on for about 20 minutes .

In Fig. 1 the time evolution of the vertical profile of the aerosol parallel volume backscattering (βp) and of the perpendicular one (βs) is shown. The depolarization ratio defined as Dep $=\beta s/\beta p$ was close to zero (less than 1%) above about 10.2 km. Only the lower layers between 10 and 10.2 km showed a non negligible depolarization, up to about 10%.

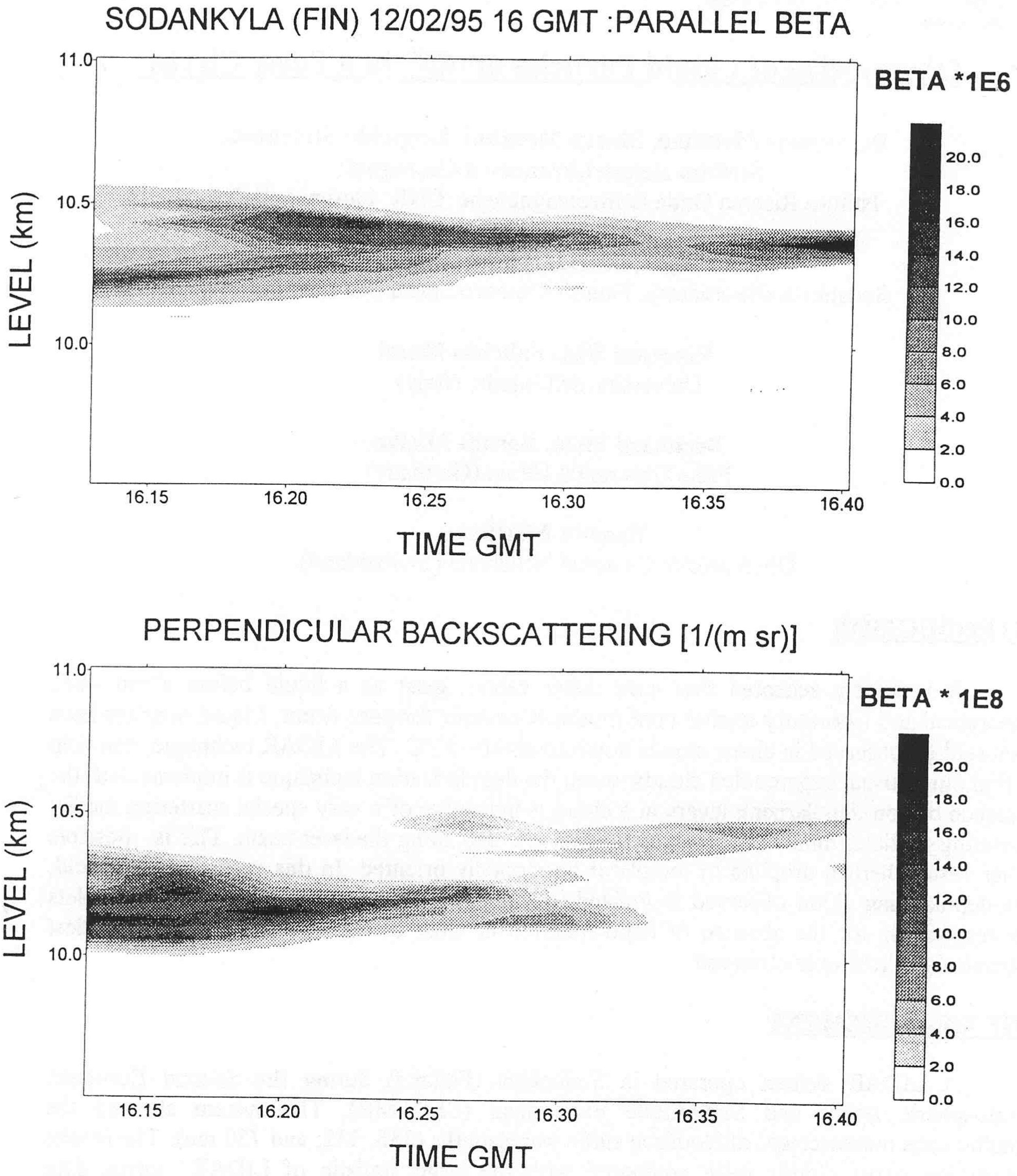


Fig. 1: Time evolution of the cloud LIDAR backscattering.. It is to be noted that the perpendicular backscattering is smaller than 1/100 the parallel one above 10.2 km, that is, depolarization ratio is smaller than 1% in such layers.

The PTU soundings of the day (Fig.2, before and after the measurement) showed the advection of warm air during the day, up to about 10 km . The temperature of the cirrus layer was between -65 and -70° in both soundings. The layer occurred at the tropopause level.

The water concentration up to the layer level increased rapidly from 12 GMT to 24 GMT, following a warm front arrival.

The isoentropic backward trajectories at 230 hPa (about 10 km) with end point above Sodankyla showed the airmass origin at different times of the day. Cold polar air arrived above Sodankyla in the morning of Feb 12. After noon, the air origin changed rapidly, and the trajectory computed for 18:00 showed the presence of rising, warm, wet oceanic air up to 230 hPa, marking the warm front arrival: Oceanic , wet air advected into the dry and cold Arctic air at the study layer height (it must be stressed that he trajectory analysis is not completely reliable in the lowest part of the stratosphere, like in this case).

The LIDAR data at 532 and 355 nm showed the same cloud integrated backscattering at both wavelengths, indicating the presence of particles larger than the LIDAR wavelength (that is, with an equivalent radius larger than about 1 micron). The vertical profiles of βs and βp showed layers with no perpendicular backscattering, and with a parallel backscattering up to 3E-5 [1/(m sr)]. Slightly depolarizing layers are also present (with depolarization<10%) , as shown in Fig.1 and Fig.3.

DISCUSSION

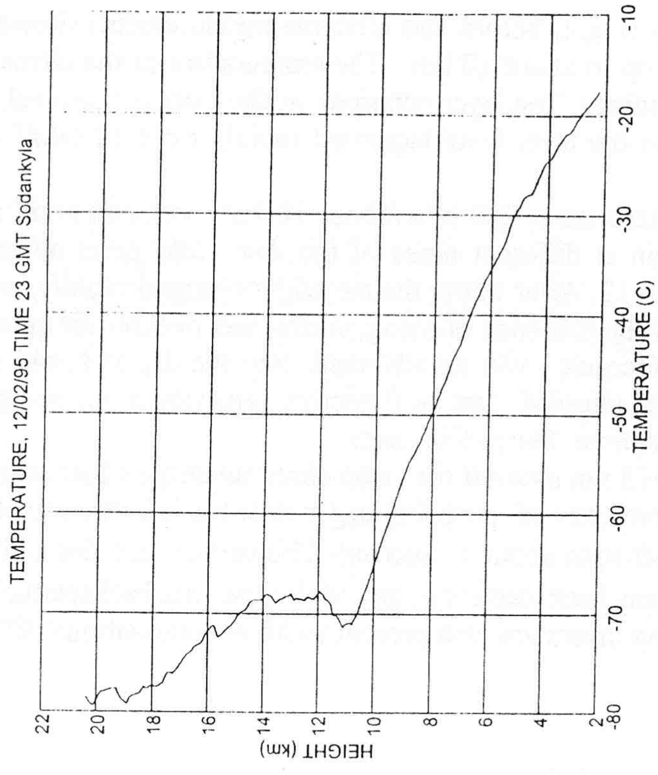
The lack of depolarization in most of the cloud layer can be explained in two ways:

1) Ice plates smaller than 1 mm can be horizontally oriented in the atmosphere, leading to an enhanced backscattering (due to specular reflection), and a very weak depolarization. Clouds containing this kind of ice crystals have been observed for example by [Platt et al.,1978]. Plates are supposed to be uncommon in the upper troposphere, below -30°C and with a low water vapour concentrations, as suggested by the works of [Pruppacher and Klett, 1978; Chen and Lamb, 1994]. Nevertheless, trigonal plates have been observed in a high cirrus at -83°C by [Heymsfield , 1986], showing that plates can be present also at very low temperatures .

The parallel backscattering (βp) values observed in our layer are comparable with those observed in "usual" polar cirrus observed below -40°C [Del Guasta et al.,1993], and are much smaller than the high backscattering values (βp>1E-3 1/(m sr)) expected theoretically by [Popov and Shefer,1994] in the case of oriented plates: an unrealistic particle density of less than 0.008/liter is required to get so low backscattering values with horizontally oriented plates. But another reason pushes to reject the hypotesis of oriented plates: in Fig.3 a single LIDAR vertical profile of the cloud is shown: the peak in the parallel backscattering corresponds to a layer with no perpendicular backscattering.

In the case of anomalous backscattering, oriented plates do enhance the parallel backscattering, but they do not deplete the depolarized signal coming from the cloud particles other than oriented plates. In order to explain Fig.3 (and the other LIDAR profiles of the same kind) in terms of oriented plates, we must suppose the presence of pure oriented plates in most of the cloud, at least above 10.2 km. It is not physical to sustain the presence of pure horizontally oriented plates (all of them with perfect parallel faces....).

2) In all available studies, it has been evidenced that pure water cannot exist as a liquid below about -40°. Theoretical [Heymsfield and Sabin, 1989] and laboratory studies [DeMott and Rogers, 1990] showed that homogeneous freezing occur very fast when cooling down water at the temperature of -40°C. But air coming from the ocean is not pure at all, because it



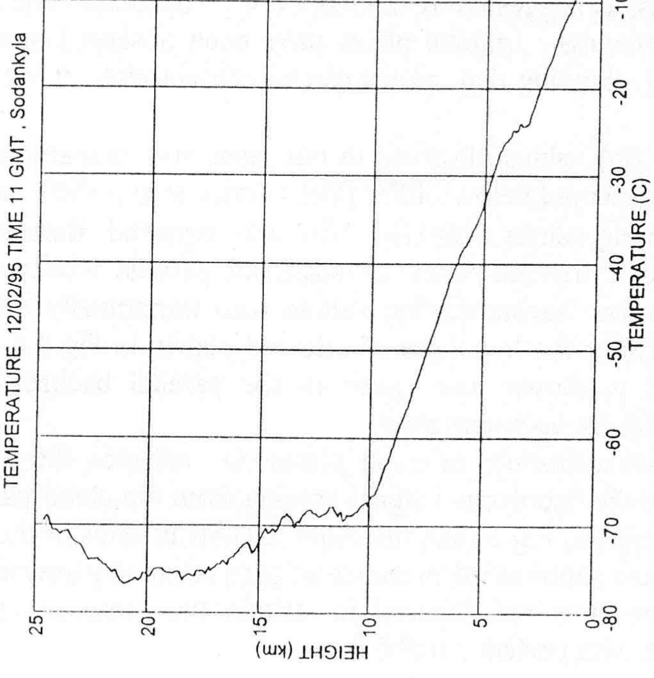


Fig.2: Sodankyla: Temperature soundings at 12 GMT and 24 GMT (before and after the cloud event)

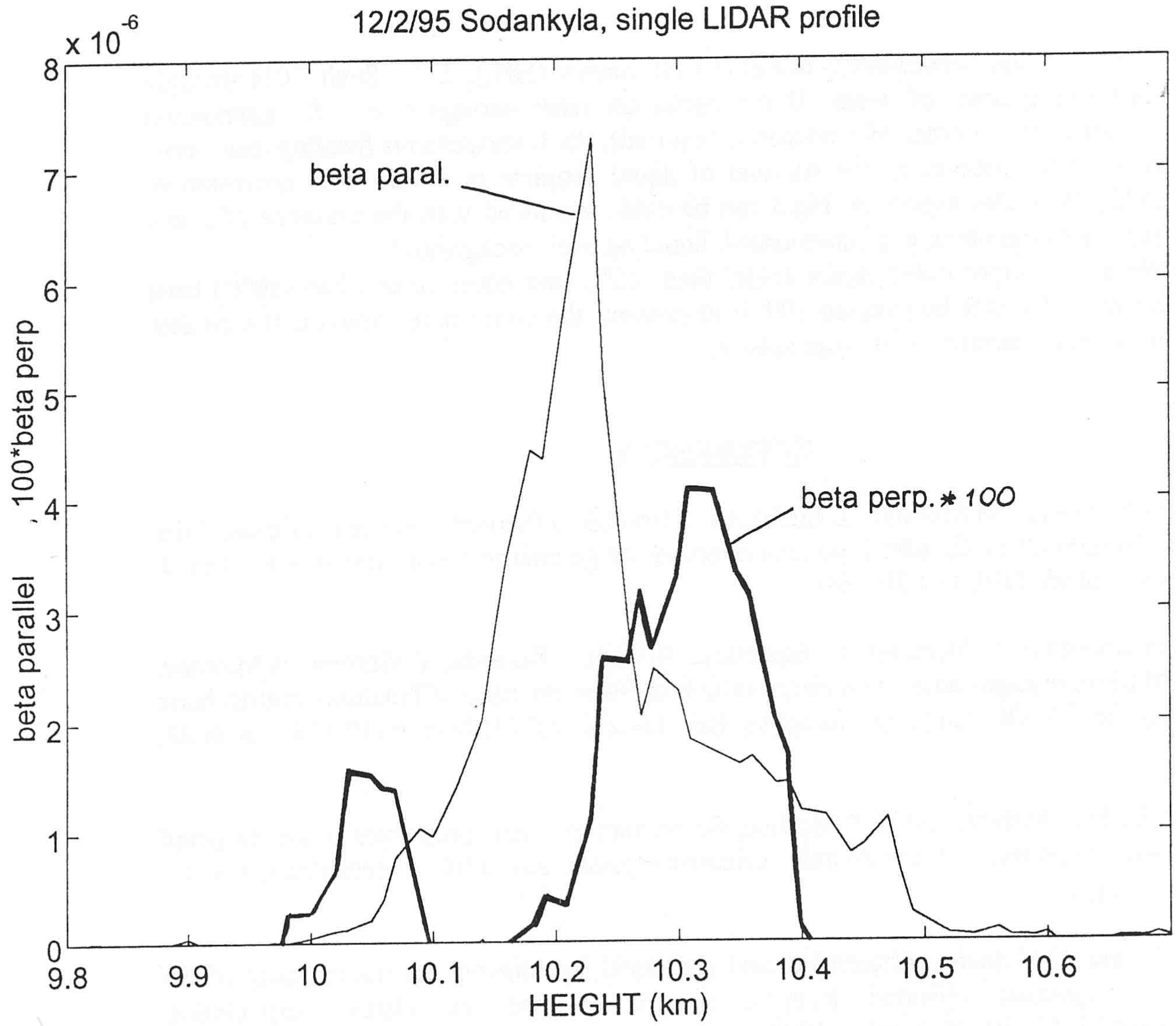


Fig.3 : A single LIDAR profile of the cloud: layers with no perpendicular LIDAR signal are evidenced, showing the presence of supercooled droplets.

contains soluble cloud condensation nuclei (CCN), mainly $(NH_4)_2$ SO_4. Such CCN strongly deplete the freezing point of water. If the nuclei are large enough (g.e. , for ammonium sulphate, a radius of the order of 1 micron is required), the homogeneous freezing can occur even below -60°C, leading to the survival of liquid droplets in a very cold environment [Sassen 1992]. With this hypotesis, Fig.3 can be easily explained with the presence of a few freezing particles originating in a supercooled, liquid aerosol background.

Only a few supercooled layers colder than -40°C (but never colder than -50°C) have been observed by LIDAR by [Sassen 1992]: at present, the cloud here shown is the coldest supercooled cloud observed in the troposphere.

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Sassen K.; Evidence for liquid-phase cirrus cloud formation from volcanic aerosols: climatic implications; Science, vol.257, 516-519, 24 July 1992.Fig.1: time evolution of the backscattering. x axis shows time (min) from 16:00 GMT.